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Ecological Changes Following Afforestation with Different Tree Species on a Sandy Loam Soil in Flanders, Belgium

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SUMMARY

The ecological effects of afforestation have been evaluated by comparing five 20-year-old homogeneous forest stands, planted on former meadowland, with the adjacent meadow and two nearby 70-year-old forest stands. About 50 physical, chemical and biological variables were measured and treated using multivariate ordination and classification techniques.

The decisive factor explaining differences of earthworm activity, litter breakdown and soil nutrient status between stands was the litter quality of the tree species. The results allowed us to predict the humus profile succession after afforestation of meadows on fairly rich substrates. The silvicultural and forest policy implications of these findings are discussed.

INTRODUCTION

An afforestation policy should outline what goals and restrictions have to be established when creating a new forest on former agricultural land. In the case of afforestation within the framework of the European set-aside policy, three important interest groups are likely to have rather different requirements. Farmers and agriculturalists are likely to require that the areas afforested should be easily convertible back to agriculture – they want soil fertility to be conserved. Conservationists are concerned about the effect of afforestation on the species diversity of sites. Modern forestry on a bio-ecological basis will strive after forest stability; as this is a necessity for multifunctional forest use and sustained yield.

The silvicultural techniques used to realize these different objectives should be based on a thorough knowledge of the ecological effects. Particular attention

should be paid to the choice of tree species as this has a crucial influence on soil development (Wittich, 1948; Rennie, 1962; Miles, 1981a; 1981b).

It is known that a certain accumulation of litter takes place after afforestation with tree species having a leaf litter that takes a relatively long time to decompose (Ovington, 1956; Babel and Benckiser, 1975; Yeates, 1988). The intensity and reversibility of the soil degradation brought about by afforestation is still a matter of discussion. Based on the observation of young conifer plantations, Ovington (1953) considered that the additional expected soil deterioration was serious enough to suggest that tree species should be chosen on the basis of their likely effect on soil conservation rather than simply to maximize wood production. Long-term trends derived from these early stages of succession could, however, be very misleading. This is because, as a consequence of successive thinnings and the final clearcut, the accumulated litter decomposes and liberates the immobilized minerals. This process can lead to the complete recovery of the soil at the end of the rotation (Page, 1962; Miller, 1988).

Tree species with an easily decomposed leaf litter, on the other hand, are believed to be able to reverse soil degradation by their ability to carry up leached base cations (Brückner *et al.*, 1987) or to increase mineral weathering rates (Miles, 1981a). Rehfüss *et al.* (1990) noticed a gradual biological regeneration of the soil after afforestation of farmland with poplars and willows. Other research, however, minimizes the soil-improving properties of certain broadleaved species (Petch, 1965).

This mini-review of the literature seems to indicate that the ecological effects of afforestation are dependent not only on the tree species but also on the initial soil conditions. Our study will try to obtain a better understanding of such ecological effects following the afforestation of a fairly rich meadow on sandy loam soil; most other studies have dealt with marginal lands.

METHODS

Five homogeneous forest stands planted almost 20 years ago on meadowland were compared with a meadow and two old forest stands nearby (Table 12.1). The comparison included the physical and chemical properties of the soil, the earthworm communities and the production and decomposition of the litter material (Table 12.2). A detailed description of the site and methods used was given in the publication by Muys *et al.* (1992). A global principal components analysis (PCA) was used in which the number of variables was reduced by pre-treating the chemical analyses of soil, holorganic layer, leaf and herbal litter in four subPCAs from which the two main principal components were extracted.

Table 12.1. Listing of the investigated stands.

Dominant vegetation	Year of origin	Former land-use	Symbol
Recent plantations			
1. *Quercus palustris*	1970	Meadow	QPA
2. *Tilia platyphyllos*	1970	Meadow	TIL
3. *Prunus avium*	1970	Meadow	PRU
4. *Alnus glutinosa*	1970	Meadow	ALN
5. *Fraxinus excelsior*	1970	Meadow	FR1
Old forest stands			
6. *Quercus robur*	1920 (approx.)	Forest	QRO
7. *Fraxinus excelsior*	1920 (approx.)	Forest	FR2
8. Meadow	?	Meadow	MEA

Source: Muys *et al.*, 1992.

Table 12.2. Listing of the evaluated variables.

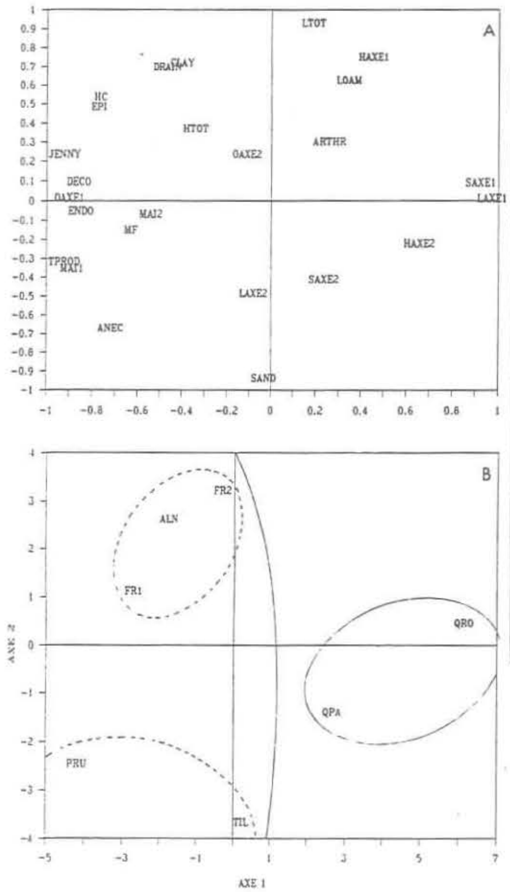
Variable	Symbol	Variable	Symbol
Annual litterfall	LTOT	Soil clay content	CLAY
Annual herb production	HTOT	Soil loam content	LOAM
Herbal ground cover	HC	Soil sand content	SAND
Epigeic earthworm biomass	EPI	Soil drainage class	DRAIN
Endogeic earthworm biomass	ENDO	Vegetation humidity index	MF
		Soil chemistry pca axe 1	SAXE1
Anecic earthworm biomass	ANEC	Soil chemistry pca axe 2	SAXE2
Total earthworm biomass	TPRO	Holorganic layer chemistry pca axe 1	OAXE1
Microarthropod density	ARTHR		
Litterbag decomposition	DECO	Holorganic layer chemistry pca axe 2	OAXE2
Deco coefficient of Jenny	JENNY		
Macrofauna activity index 1	MAI1	Leaf litter pca axe 1	LAXE1
Macrofauna activity index 2	MAI2	Leaf litter pca axe 2	LAXE2
		Herbal litter pca axe 1	HAXE1
		Herbal litter pca axe 2	HAXE2

Source: Muys *et al.*, 1992.

RESULTS

The global PCA detected the biological and chemical soil fertility as the most important source of variation between the stands (42%) on the first axis. The variables mainly contributing to the formation of this axis were litter decomposition (DECO, JENNY), earthworm biomass and activity (TPRO, ENDO, MAI1) and nutrient reserves in litter, holorganic layer and soil (LAXE1, OAXE1 and SAXE1) (Fig. 12.1a).

The independent variables *in casu* soil humidity (DRAIN, MF) and texture (CLAY, SAND, and LOAM), intervene little or not on the first axis, which suggests that the tree species is the main cause of variation. The classification of the stands regroups both the young and the old *Quercus* stands on the poor side of



GLOBAL ANALYSIS

% OF VARIABILITY EXPLAINED :

AXE 1	AXE 2	AXE 3
42	23	14

CORRELATION VARIABLES/AXES :

VARIABLE	AXE1	AXE2	AXE3
SAXE1	0.85	0.01	0.1
SAXE2	0.05	-0.17	-0.34
OAXE1	0.81	0	0
OAXE2	-0.01	0.06	0.77
LAXE1	-0.94	0	-0.02
LAXE2	-0.01	-0.23	-0.02
HAXE1	0.21	0.57	-0.15
HAXE2	0.43	-0.05	0.32
LTOT	0.04	0.87	0.04
HTOT	-0.12	0.14	-0.54
HC	-0.59	0.29	-0.05
EPI	-0.6	0.24	0.01
ENDO	-0.73	0	-0.04
ANEC	-0.54	-0.44	0.04
TPRO	-0.85	-0.1	0
ARTHR	0.07	0.09	-0.16
DECO	-0.74	0.01	0.11
MAI1	-0.79	-0.09	0
MAI2	-0.29	0	0
JENNY	-0.85	0.06	0
CLAY	-0.16	0.52	0.18
LOAM	0.12	0.4	-0.19
SAND	0	0.87	0.01
DRAIN	-0.22	0.51	0.13
MF	-0.4	-0.02	-0.34

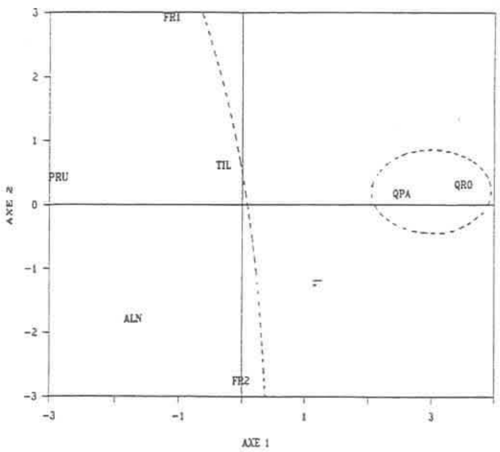
Fig. 12.1. Global Principal Components Analysis (Muys *et al.*, 1992). A, ordination of the variables. B, ordination/classification of the stands.

the first axis; the other stands, together with the meadow on the rich side (Fig. 12.1b). The origin of the differences observed was found in the classification of leaf litter, based on the ordination of leaf litter quality. The quality of the *Quercus palustris* leaf litter is low and very similar to that of *Quercus robur* (Fig. 12.2).

The litter quality has its repercussions on the decomposition rate. An ANOVA of the holorganic layer of the five young plantations (Table 12.3) found significantly ($P < 0.001$) higher amounts of litter under *Quercus palustris* (727 g/m^2) than under the other species (5–96 g/m^2), except *Tilia platyphyllos* (136 g/m^2), where a certain accumulation took place caused by *Fagus* leaves blown in from the adjacent old stand.

The organic acids produced in the accumulating fermentation layer migrate into the mineral soil and are expected to affect its nutrient status. Although the stand classification (based on the ordination of their soil nutrient concentration) still clusters the *Quercus palustris* stand together with the other young stands and the meadow at the rich side of the first axis (Fig. 12.3), its pH value (at 0–5 cm) is already significantly ($P < 0.001$) lower (pH 4.97) than that of the young *Fraxinus* (pH 6.08), *Prunus* (pH 5.54) and *Alnus* (pH 5.51) stands. It is also somewhat, but not significantly, lower than that of *Tilia* (pH 5.26) and the meadow (pH 5.18) (Table 12.4). It is interesting that all the young stands and the meadow too had a significantly lower pH than the original meadow (pH 6.4) (De Coninck, 1972). This overall pH decrease is mainly due to the lack of artificial fertilization following the planting of the trees.

A decreasing pH has a negative influence on the earthworm biomass ($r = 0.72$, $P < 0.001$). The ANOVA of the earthworm biomass ($P < 0.001$) detected significantly lower values under *Quercus palustris* (344 g/m^2) than under



CHEMISTRY OF LEAF LITTER PRODUCTION

% OF VARIABILITY EXPLAINED :

LAXE1	LAXE2
40	26

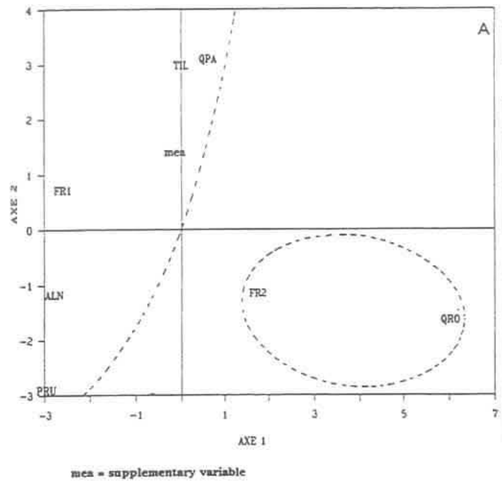
CORRELATION VARIABLES/AXES :

VARIABLE	LAXE1	LAXE2
C	0.18	0.24
N	-0.21	-0.4
C/N	0.34	0.51
P	-0.29	0.43
K	-0.82	0.04
Na	0.01	-0.33
Ca	-0.95	0
Mg	-0.54	0.17
Mn	0.3	-0.49
Fe	-0.46	-0.1
Al	-0.36	-0.14

Fig. 12.2. Ordination/classification of the leaf nutrient content in the stands (Muys *et al.*, 1992).

Table 12.3. ANOVA of the holorganic layer biomass (g/m²), where $F = 4.179$ and significance level = 0.0128.

Stand	Average (g/m²)	Multiple range test (95% confidence interval)	
QPA	727	*	
TIL	136	*	*
PRU	96		*
ALN	63		*
FR1	5		*



CHEMISTRY OF THE SOIL (0-5 cm)

% OF VARIABILITY EXPLAINED :

SAXE 1	SAXE2
56	29

CORRELATION VARIABLES/AXES :

VARIABLE	SAXE1	SAXE2
C	0.35	-0.64
N	0.04	-0.72
C/N	0.44	-0.32
P	-0.41	-0.13
K	-0.49	0
Na	-0.41	-0.03
Ca	-0.82	0
Mg	-0.52	-0.97
Mn	-0.58	0.14
Fe	0.8	-0.04
Al	0.84	-0.82
CaCO3	-0.64	-0.22
PH(H20)	-0.92	0.03
EXCH.BASE CATIONS	-0.78	-0.02
TOTAL C.E.C.	0.02	-0.95
BASE CATION SATUR.	-0.94	0

Fig. 12.3. Ordination/classification of the soil nutrient concentration in the stands (Muys *et al.*, 1990).

Prunus, *Fraxinus* and the meadow (989–1334 g/m²) and distinctly, but not significantly lower values than under *Alnus* and *Tilia* (673–712 g/m²) (Table 12.5).

The herbaceous vegetation in the stands does not yet reflect the soil changes that have taken place. The present-day meadow still has the same vegetation type as the original meadow, dominated by grasses such as *Dactylis glomerata* and *Holcus lanatus*. The young forest stands all have a vegetation mainly dominated by *Urtica dioica*. The herbaceous above-ground biomass produced yearly is dependent on the amount of light penetrating the canopy and can vary from the almost complete absence of vegetation under the relatively dense canopy of *Tilia*

Table 12.4. ANOVA of the mineral soil pH (H_2O) at 0–5 cm, where $F = 12.998$ and significance level = 0.0000.

Stand	Average	Multiple range test (95% confidence interval)		
QPA	4.97	*		
MEA	5.18	*	*	
TIL	5.26	*	*	
ALN	5.51		*	
PRU	5.54		*	
FR1	6.08			*

Table 12.5. ANOVA of the earthworm biomass (g/m^2), where $F = 6.167$ and significance level = 0.0008.

Stand	Average (g/m^2)	Multiple range test (95% confidence interval)		
QPA	344	*		
ALN	673	*	*	
TIL	712	*	*	
FR1	989		*	*
MEA	1017		*	*
PRU	1334			*

to a maximum 350 g/m^2 under the sparser canopy of *Quercus palustris*. The old stands are dominated by perennial herbs, *Fraxinus* by *Anemone nemorosa* and *Lamium galeobdolon*; *Quercus robur* by *Rubus fruticosus* and *Pteridium aquilinum*.

The species diversity in the herb layer was quite variable. The original meadow contained 14 species, while the untreated meadow today has 20 species, the *Quercus palustris* stand 10, *Alnus* 13, *Prunus* 18, *Fraxinus* 24 and the *Tilia* stand 30. The old *Quercus robur* stand has 7 and the old *Fraxinus* stand has 33. Typical species of woodlands with a mull humus (like under the old *Fraxinus* stand), such as *Dryopteris filix-mas, Arum maculatum, Polygonatum multiflorum, Ficaria verna* and *Adoxa moschatellina*, have started to appear – especially under the young *Prunus* and *Fraxinus* stands. None of the young stands has developed vegetation consisting of acid-loving woodland species as is found in the old *Quercus robur* stand.

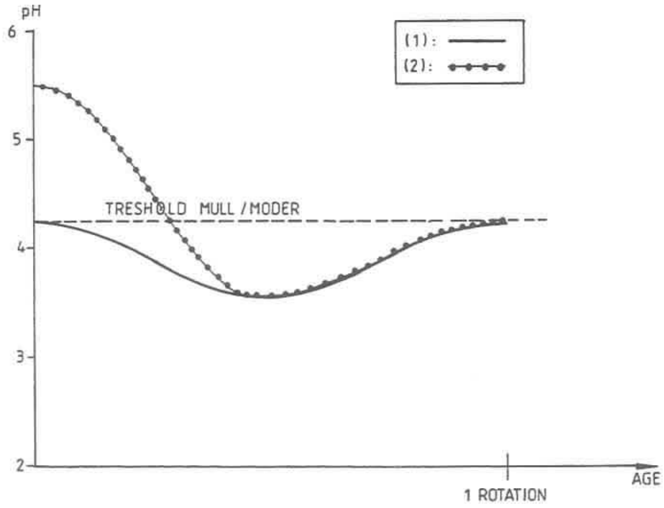


Fig. 12.4. Time sequence graph of the pH evolution following afforestation with tree species having refractory litter. (1) acid initial soil condition (Page, 1962), (2) neutral initial soil condition.

Discussion

After 20 years of forest development on a former meadow, significant differences in several biological and chemical ecosystem variables could be detected under different tree species. In the *Quercus palustris* stand in particular the poor quality of the litter resulted in litter accumulation and was thus the triggering factor leading to the chemical impoverishment of the soil.

A complete recovery of the soil at the end of the rotation, as suggested by Page (1962) and Miller (1988) cannot be expected in soils with a topsoil pH of more than 4.5 but without free $CaCO_3$. The degradation will pass a threshold that is irreversible unless expensive ameliorating measures like liming are carried out (Fig. 12.4). Based on the ordination and classification of 25 forest stands in Flanders (Belgium), Muys and Lust (1992) set threshold at a pH(H_2O) of 4, a C/N-value of 14 and a base cation saturation of 30% in the topsoil (0–5 cm).

The ecological explanation for this threshold is two-fold. First, at this level of acidity all burrowing earthworm species, both endogeic and anecic, disappear. Endogeic earthworms are pale-coloured soil-living earthworms. They ingest humus-rich soil and in this way create horizontal gallery systems in the first 30 cm of mineral soil. Anecic earthworms are dark-pigmented earthworms that build deep, vertical galleries. At night they feed on litter from the soil surface (Bouché, 1972). The gradual decrease in abundance of earthworms slows down litter decomposition and almost stops the mixing of soil from different layers; it

establishes a vicious circle of biological, chemical and physical soil degradation. Moreover, once the earthworms have gone, their recolonizing capacity is very restricted. This was illustrated in a 80-year-old maple stand, following a beech rotation, on a rich, loamy soil. Despite the fact that good litter was produced, the soil had not become an active mull humus again because of the lack of burrowing earthworms in the surrounding area (Muys, 1989). Second, the soil passes from the exchange-buffer range into the aluminium-buffer range at a pH of 4.2 (Ulrich, 1983). The more the exchange surfaces are saturated with aluminium plus iron the more their Ca/Al and Mg/Al selectivity decreases and the more difficult it becomes to absorb base cations (Hildebrand, 1991).

These considerations lead us to the conclusion that afforestation of meadows that have an active earthworm community results in the humus developing in one of two ways. The mull humus is maintained if most of the litter produced is of good enough quality; if this is not the case the mull humus develops into a moder humus (Fig. 12.5).

How can these assessments be interpreted if one of the aims of forest management is stability? Van Miegroet (1990) mentions loss of internal regulation over the movement of mineral soil nutrients as one of the main causes for forest degradation. Ulrich (1981, 1983) considers soil acidification and cation leaching as the main threat to forest stability and Wittich (1963) states that mull humus is desirable in all aspects – especially for water economy and nutrient status. Additional factors that must be considered include the continuous external proton loads due to air pollution and the fact that more than three-quarters of the forest area of Flanders is already situated in the aluminum- or iron-buffer range. If all these factors are taken into account it is clear that all tree species that are known to cause soil degradation should be excluded from the afforestation of agricultural land in Flanders. Silviculture on these soils must concentrate on the cultivation of valuable broadleaved species such as ash, maple and cherry. Plantations of fast-growing pioneer species such as poplar, willow and alder are also acceptable.

To what degree trees with leaf litter that takes a relatively long time to decompose, such as *Quercus* spp., can be tolerated in a tree species mixture, given that the mull humus must be maintained, remains an open question and certainly needs more research. It is likely, however, that it depends highly on the initial biomass of anecic earthworms present: anecic-poor mulls such as the *Alnus* stand are much more sensitive to litter accumulation than anecic-rich mulls such as the *Prunus* stand (Muys *et al.*, 1992).

The afforestation of meadowland appears to result in an increase in the species diversity of the ground flora. This is comparable with what Rehfüss *et al.* (1990) found for afforested arable land. The dominance of *Urtica dioica* can be reduced by underplanting a substorey of shade-tolerant shrubs, such as *Corylus avellana*, *Cornus* spp., *Viburnum opulus*, *Alnus glutinosa* and so forth. Under these conditions, typical woodland species will begin to colonize the plantation relatively quickly so long as old woodland still exists nearby (see Chapter 3).

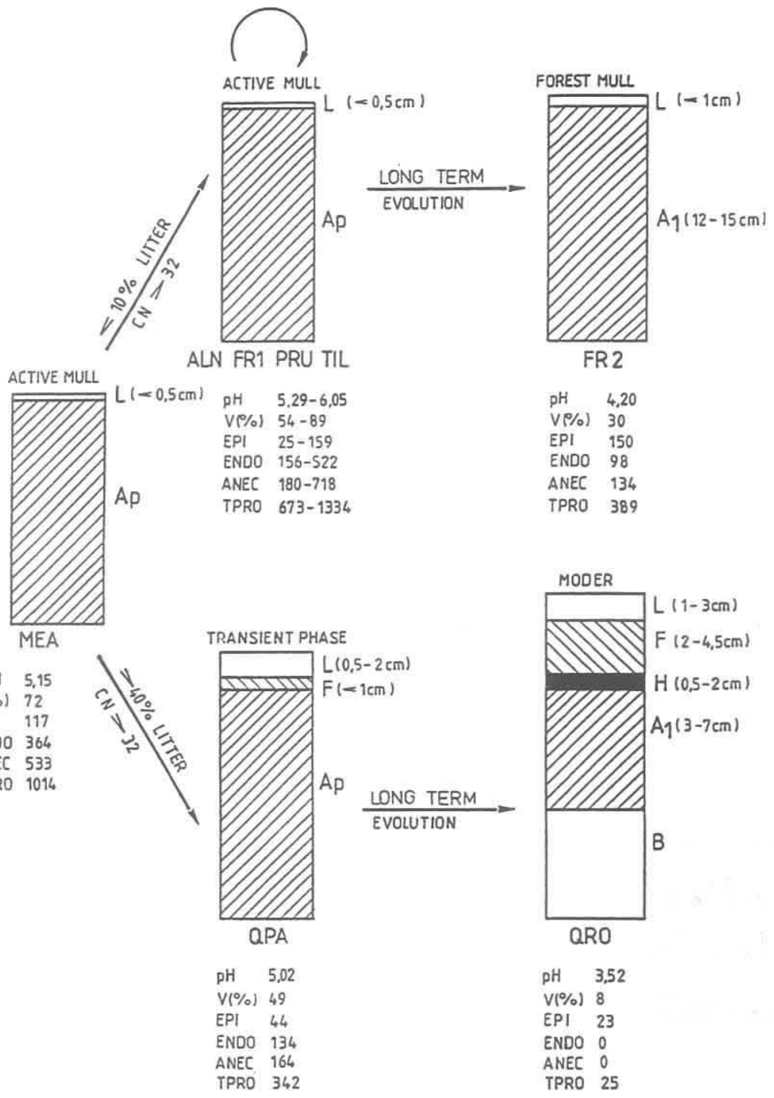


Fig. 12.5. Scheme of the evolution of the earthworm community, the humus type and the soil properties following afforestation of a meadow with different tree species (Muys *et al.*, 1992).

CONCLUSIONS

In summary, our main conclusions are as follows. First, the use of a tree species with litter that takes a long time to decompose in afforestation of meadowland on a sandy loam soil leads to litter accumulation and soil acidification. Second, this degradation is likely to be irreversible when topsoil pH decreases below pH4, as below this threshold earthworms disappear and the soil enters the aluminum-buffer range. Third, forests with mull humus are more resistant to external proton loads than forests with moder humus and hence mull humus is preferable for maintaining forest stability. Fourth, when good-quality soils are afforested, trees with high-quality litter, including valuable broadleaved species such as ash, cherry, maple or walnut, and fast-growing species such as poplars and willows, should be used. Finally, under these species, an interesting vegetation can develop. Typical woodland herbaceous species will appear, depending on the amount of light and the distance from old woodlands.